United States
Department of
Agriculture

Soil
Conservation
Service

**Assessment
and
Planning**

Assessment and Planning Staff Report

#523

Forum on Erosion Productivity Impact Estimators

James A. Maetzold
Klaus F. Alt

A and P Staff Report,
Appraisal and Program
Development Division
April 1986

Forum On Productivity Impact Estimators, May 8-9, 1985, James A. Maetzold, Soil Conservation Service and Klaus Alt, Economic Research Service, U.S. Department of Agriculture.

ABSTRACT

In 1980, the USDA formed the National Soil Erosion - Soil Productivity Research Planning Committee to identify what information and research directions are needed to estimate the effects of soil erosion on soil productivity. A number of erosion estimators have been developed and field experiments have been undertaken since 1980 as a result of this effort. This forum reviews: criteria for modeling soil erosion-soil productivity relationships, accomplishments in modeling and other soil erosion estimators, comparisons of results, and identification of needed improvements. This report contains documentation of the accomplishments during the 1980 to 1985 period.

Keywords: Soil erosion, erosion-productivity, simulation model, field experiments

with other economic components for the 1985 RCA appraisal will provide some of this information. And then I think one of the things that we need to think about regarding EPIC is what is its potential role in international programs. That is an issue that the agencies are addressing.

We are looking for the advice and counsel of the researchers, the program managers, and the users of EPIC inputs and outputs to provide some guidance for us in the decisions we are going to make over the next several days about where we go with EPIC. Hopefully, this forum will achieve those kind of results.

THE EFFECT OF EROSION ON PRODUCTIVITY: ROLE OF MATHEMATICAL MODELS

By Kenneth Renard and Donald Meyer

Introduction

The advances in digital computer modeling have closely paralleled the development of computers in general. As computers have decreased in price and physical size, yet increased in problem solving capacity and speed, our ability as scientists and engineers to emulate prototype systems has progressed until we can often postulate models that are more complex than our ability to make prototype measurements with which to validate the model components. Simultaneous with developments in computer software and hardware have been developments of graphic capability which help facilitate interpretation of computer simulation, both in space and time.

The United States Congress recognized the potential of models in the successful planning and management of water resources. Congress instructed the Office of Technology Assessment (OTA) to (1) assess the nation's ability to use models efficiently and effectively in analyzing and solving water resource problems and (2) make recommendations for improving the use of available technologies.

The OTA Report (1982) had some interesting comments about mathematical models. The following quote pertinent to model development is from the OTA Report: "Mathematical models are among the most sophisticated tools available for analyzing water resource issues. They can use the capabilities of today's digital computers to perform and integrate millions of calculations within seconds in order to understand and project the consequences of alternative management, planning, or policy-level activities. Models not only assist in decisionmaking--they provide information that people must interpret in light of existing laws, political and institutional structures, and informed professional and scientific judgment. Nonetheless, models can significantly improve the informational background on which decisions are based, and substantially reduce the cost of managing water resources."

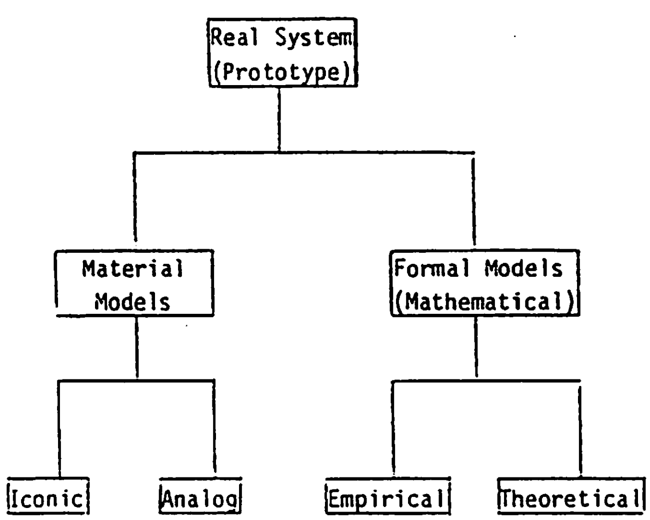
The objectives of this paper are:

1. To introduce the concept of modeling for predicting the effect of erosion on soil productivity,
2. To illustrate how conceptualization in a model can lead to parameter distortion,
3. To illustrate the importance of model flexibility for problem solving,
4. To describe the processes of developing an operational model,
5. To describe some limitations for model use, and
6. To project some future trends in natural resource models.

Modeling Semantics

Much material has appeared in recent years regarding model classification. In an excellent introduction to the subject, Woolhiser and Brakensiek (1982) point out that although criteria used in model classification vary (the criteria vary with special interests or the needs of a particular discipline), models can generally be classified as either "formal" or "material" as suggested 40 years ago by Rosenblueth and Wiener (1945). A formal (intellectual) model is a symbolic, usually mathematical, representation of an idealized situation that has an important structural property of the real system. This is the most common model type used in natural resource problem solving. A material model is a physical representation of a complex system by a system having a simpler structure than the real system, yet preserving the most important properties of the prototype. The iconic model (a look-alike) is a simplified version of a prototype system which uses the same materials as a prototype (e.g., a hydraulic model uses a fluid although not necessarily the same as the prototype fluid). Rainfall simulators, lysimeters, and experimental watersheds are other examples of iconic models. In an analog model, the model quantities measured are of a different substance than in the real system. One of the most common analog models is one which measures the flow of electric current to represent the flow of water. Material models were dominant in water resource problem solving up to a decade or so ago, but they have been largely replaced by mathematical models. However, the results of experiments with rainfall simulators, lysimeters, plots and experimental watersheds provide most of the validation tests for mathematical models.

Figure 1.--Model classification (Woolhiser and Brakensiek, 1982).



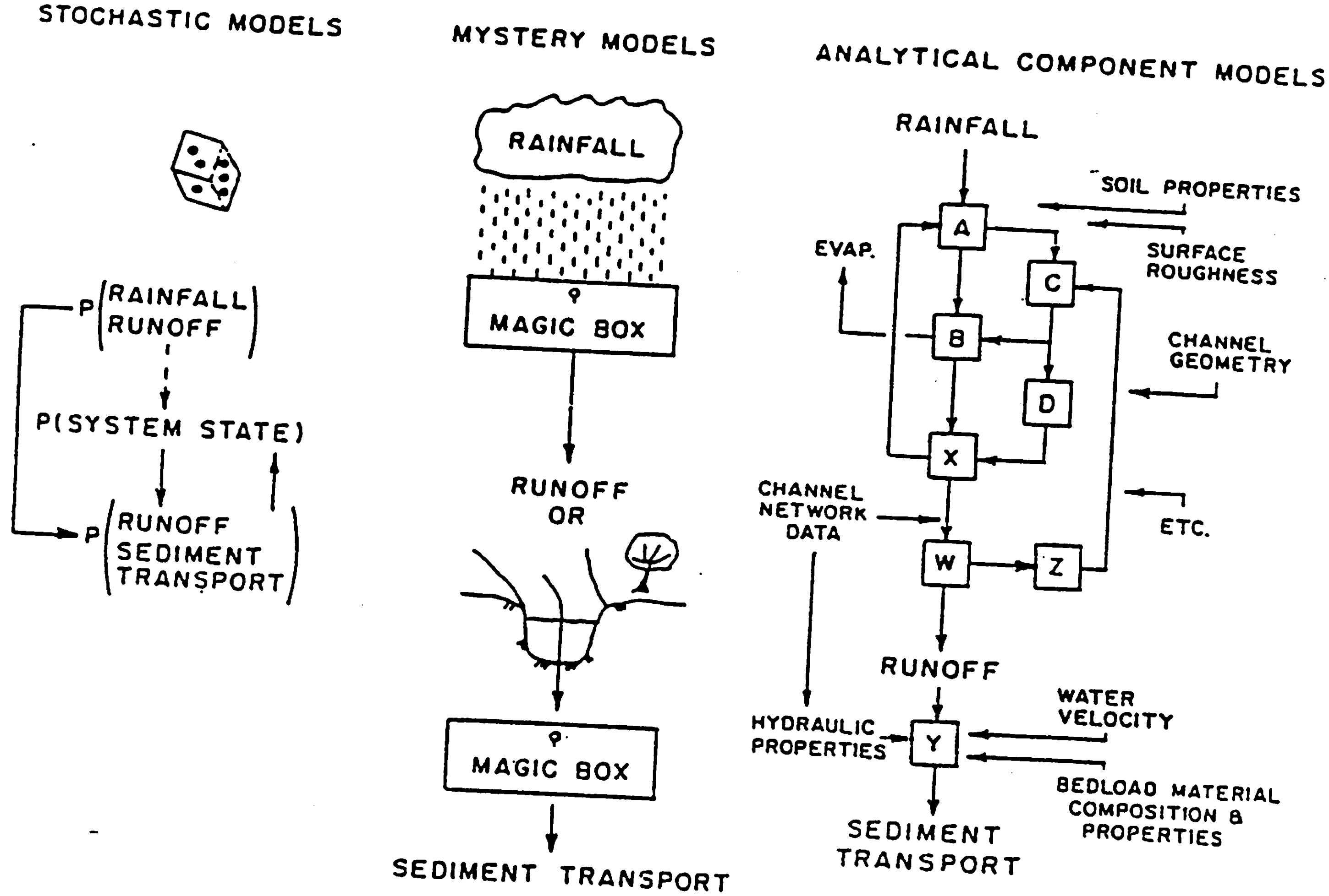
A theoretical model includes both a set of general laws, or theoretical principles, and a set of statements of empirical circumstances. On the other hand, an empirical model omits general laws (e.g., law of physics), and is, rather, a representation of real-life data (the Universal Soil Loss Equation (USLE) being a well known example). Thus, in an empirical model such as a regression relationship, two variables may appear to be physically related (and thus a theoretical model) when, in fact, they are not. A schematic diagram of this model classification is shown in Figure 1.

On a more practical sense, the techniques used in mathematical modeling involve a conceptualization as illustrated in Figure 2. In a stochastic model, the probabilistic nature of the system is preserved, with occurrences often having a time- or space-dependent structure; whereas a purely probabilistic system is time- and space- independent. Thus, in a stochastic model, the structure and the distribution characteristics of variates are determined from sample data (sample functions) and Monte Carlo techniques are often used to produce synthetic sequences of the variates because analytic results often cannot be obtained for realistic models.

Mystery (also called "magic" or "black box") models utilize a given input which, when converted by a mathematical transformation or function (they may have physical significance), produces the output. Such approaches have been widely used by hydrologists to convert rainfall excess to a runoff hydrograph by a unit hydrograph technique.

Finally, the analytical component model uses the physics of a process(es) to produce the required output. Although this type of modeling approach may be the most expensive of the three approaches (because it requires more algorithms, increased computer time, and extra field data), it should provide the most reliable results (assuming parameter values are known), especially when management alternatives are to be evaluated. This modeling approach is used extensively throughout the EPIC model (Williams et al., 1983), although the climate routine of the model uses stochastic principles. Such component models are often termed causal models in the literature.

Figure 2. Commonly used approaches for mathematical modeling of sediment transport.



De Coursey (1983) points out that dynamic "causal" descriptions of the subprocesses involved in a particular problem solution aid in

"(1) structuring the data collection program, (2) studying the response of a research site, (3) selecting and evaluating parameters, (4) determining the accuracy used in evaluating input variables and parameters through sensitivity analyses, (5) studying the significance of spatial and temporal variability of physical features such as infiltration, and (6) determining how many observations are needed to achieve a given degree of accuracy in a specified period of time."

Why Model The Effect of Soil Erosion on Soil Productivity?

Many complex cause-effect relationships are involved in the way soil erosion affects soil productivity. For example, the fact that erosion reduces the soil depth and thereby the moisture reservoir for plant growth is well accepted. We also know that erosion changes soil surface characteristics which may affect infiltration. Erosion also changes soil physical and chemical properties which, in turn, affect the potential of the pedon to produce a crop. Given these interrelationships, plus the climatic variations across the United States, the thousands of different soils involved, and the different tillage and cropping systems, the net result is a maze of combinations that are difficult to "put together" in an objective way. By using a computer simulation model we have a feasible means to facilitate the many computations required to achieve the mandates of PL 95-192, the RCA legislation.

Many years ago in their discussion of the role of models in science, Rosenblueth and Wiener (1945) stated:

"No substantial part of the universe is so simple that it can be grasped and controlled without abstraction. Abstraction consists in replacing the part of the universe under consideration by a model of similar but simpler structure. Models . . . are a central necessity of the scientific procedure."

Chris Johannsen (1983), past president of the Soil Conservation Society of America, stated, "The failure to consider seriously the use of computers in your work could make the difference in future advancement." Testimonials such as these are common occurrences in natural resource scientific literature.

The OTA report on Water Resource Models (1982) points out that:

> "Mathematical models have significantly expanded the Nation's ability to understand and manage its water resources. They are currently used to investigate virtually every type of water resource problem; for small- and large-scale studies and projects; and at all levels of decisionmaking. In some cases, models have increased the accuracy of estimates of future events to a level far beyond 'best judgment' decisions. In other areas, they have made possible analyses that could not be performed empirically, with or without computer assistance. Further, models have made it feasible to quantitatively compare the likely effects of alternative resource decisions.
>
> Models are often the best available alternative for analyzing complex resource problems. While many of the economic and social factors in water resource decisions cannot be fully enumerated, models can be used to integrate the available data, and provide estimates of future effects and activities. Such estimates are highly useful in evaluating the consequences of different resource policy options, and are often less expensive than conducting comprehensive surveys and using other traditional approaches.
>
> Models have the potential to provide even greater benefits for water resource decisionmaking in the future. As models are refined and receive wider acceptance, they will be able to increase the efficiency of water resource management and encourage cost effective decisionmaking. Such models can do much to increase the rationality of regulations and the standard-setting process, and can generally provide a sound scientific basis for water policy."

To address the question of the impacts of soil erosion on agricultural productivity, it was necessary to develop a model incorporating many of these features. The resulting model (and the computer simulation program implementing the model) is called EPIC for Erosion Productivity Impact Calculator. As the EPIC model was conceptualized, programmed, and evaluated, the following important criteria were considered:

Availability of data

Degree of accuracy required

Computational time necessary

Balanced approach to the entire system.

Such items are a part of the model building not only for EPIC and PI (Larson, et al., 1974), but for modeling in general. Since we feel sure that others that follow on the program will elaborate on this topic, we will proceed to other items regarding model development.

Models must be capable of considering several "shocking" facts in an orderly manner, and EPIC is no exception. For example, an annual rainfall of 30 inches over an area of 1 mi^2 amounts to several quadrillion (? x 10^{15}) drops with a volume of more than 500 million gallons. These drops have an impact energy (kinetic energy) of 30 billion foot-pounds, an amount equal to the energy of 10,000 tons of TNT. Thus, a soil erosion-productivity model must consider the temporal and spatial variability of precipitation, plus maintain a mass balance for both the water and the energy involved. Further problems that the model must accommodate are illustrated with respect to specific characteristics of the rainfall and runoff in Table 1.

Table 1.--Differences between erosive rainfall and runoff which must be reflected in a physically-based erosion-productivity model.

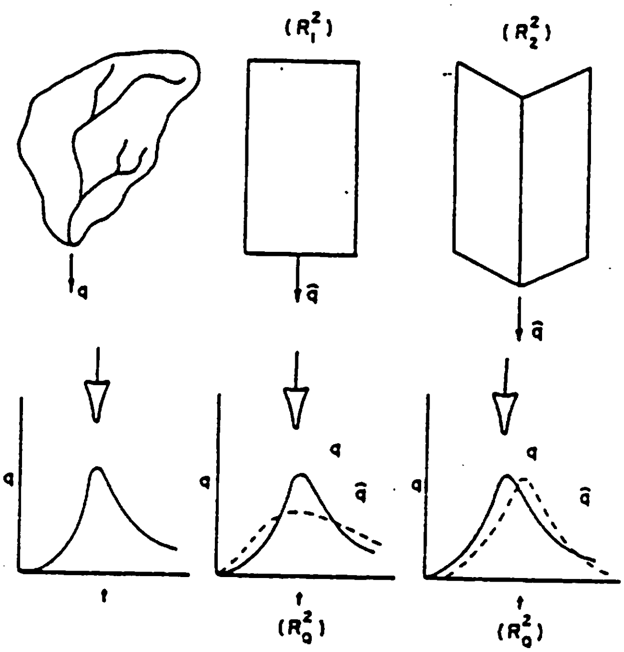
Characteristics	Rainfall	Runoff
Direction	Downward	Near horizontal
Area affected	Entire area	Small part
Erosive potential	All	Only part
Velocity	Up to 30 ft	Less than 3 ft/s
Form	As drops	Accumulations

Conceptualization of the Effect of Erosion on Productivity: Parameter Distortion

Whereas erosive rainfall occurs over an entire area, runoff affects only a portion of the area. Numerous other aspects are important for developing a model that is capable of emulating the soil erosion-productivity problem, including nutrient cycling, disturbance to the soil from tillage/harvest operations, plant growth problems, etc. The EPIC model accommodates these interrelated processes with algorithms, many of which have feedback mechanisms such that alterations in some segment (or model subroutine) have a cascading effect on other components. Although the human mind can comprehend how all these actions and interactions occur, formulation in a computer model greatly facilitates the quantitative description of these interactions.

The soil block (pedon) shown in Figure 3 is the computational element used in the EPIC model.

Figure 3.--Computational model of soil block (pedon) used in EPIC.



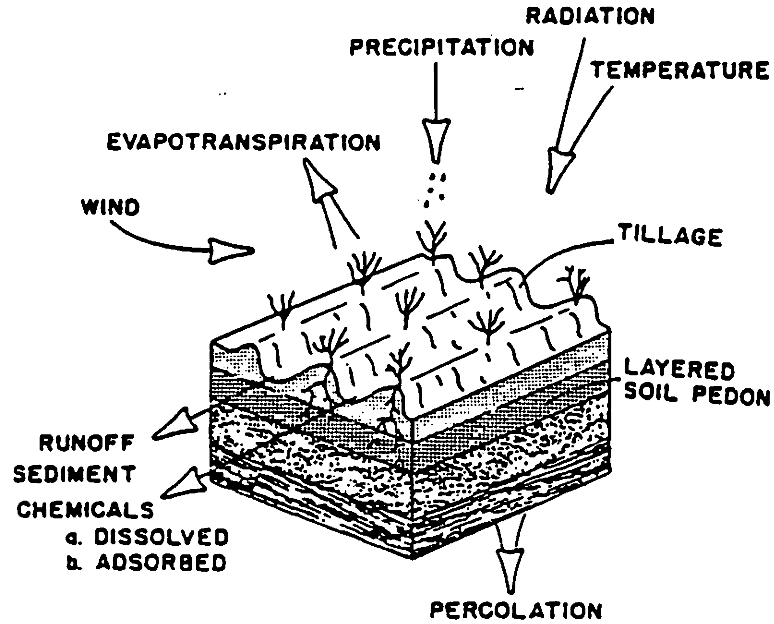
Although this model considers the layers of soil contained in such a block, it does not consider the micro changes that occur in such a system due to the creation of macro-channels from rodents, root decay, etc., nor the consolidation of the surface soil following tillage and the associated disappearance of such macropores. Thus, in some respects, the model allows spatial variability, and in other cases does not.

Such problems have long perplexed modelers; the problem has been addressed in hydrologic literature at various times. Lane and Woolhiser (1977) used kinematic flow equations to illustrate how runoff from a natural watershed shown schematically in the upper left portion of Figure 4 produces the observed hydrograph, q, in the lower left portion of the figure. A single plane (upper center portion of Figure 4), fit to the topographic data (x, y, z coordinates) and producing R_1^2 as a geometric goodness-of-fit statistic, then yielded the hydrograph labeled q in the lower center graph. From the observed (q) and fitted (q) hydrographs, a goodness-of-fit statistic, R_G^2, was obtained. The same procedure was completed for a Woodling configuration (open book on the upper right portion of Figure 4) which produced further goodness-of-fit statistics. The computer program used in this effort produces optimal hydraulic roughness values for the planes and channels, separately.

The point to be made is that by increasing the number of planes and channels, and thereby increasing the geometric goodness-of-fit (model to prototype) and the resulting geometric goodness-of-fit statistic, the parameter values become less distorted. Optimal roughness parameter estimates will likely increase as the geometric distortion in simplified models decreases. More realistically, parameter values from similar experiments may differ because of different distortions imposed in the model emulation of the prototype. For example, a common problem in hydrologic modeling involves use of the Manning equation for channel flow. The roughness term "n" used in this algorithm often differs from textbook or handbook values. In a simulation model, the straight channel approximation of a real channel (Figure 4) results in using an artificial roughness value in the model that is actually a fitting, optimization, or tuning coefficient.

Problems such as these are common to all models--EPIC and PI being no exceptions. The real problem is in defining how limiting these assumptions are to the objectives of the project for which the model was designed to provide guidance. In the EPIC model, topographic approximation is used to represent a "typical" pedon and slope in a Land Resource Area. Furthermore, a generic soil description is used, along with typical agronomic practices (planting, tillage, harvesting, etc.), and a stochastic climate sequence for a specific year. That these conditions may or may not represent what might be measured for a specific prototype condition must be recognized. If, on the other hand, the results are used to compare crop yields from alternative management practices, the resulting data, expressed as differences or ratios, may be very realistic.

Figure 4.--Schematic representation of a watershed, simplified models, and associated goodness-of-fit statistics (Lane and Woolhiser, 1977).



Model Flexibility

It is probably not necessary to enumerate how models can be used to assist with decision making. We assume that most of you have experience with modeling in some way or form. What is important to realize is that modeling (and especially modeling of complex systems) may be revolutionary in its original conceptualization, but it is generally followed by an evolutionary process where it undergoes refinement and fine tuning.

A model is a formalized presentation (in a mathematical sense) of what our mind perceives or expects might happen for a given set of external perturbations. The advantage of the mathematical representation is that such an explanation should be understood the same way by everyone. If other reviewers do not agree that this is the way things would likely happen (based on their experimental data or experience), they can suggest an alternative for one or more algorithms of the model, and further hypothesis testing can proceed; thus, the idea of model evolution. Furthermore, new subroutines can be added or substituted as more new knowledge becomes available, or as the objectives for the model change.

Flexibility has been an essential consideration in the development of the EPIC model. Although the basic concept of considering such major components as climate, hydrology, erosion, plant growth, tillage, etc., has been preserved since the first meeting of the modeling group at Mississippi State University in May 1981, numerous changes have been made in the subroutines. The result is that we are to hear a description of the EPIC model in the forum that may well be the 25th version. Without question the simulated answers of how erosion affects productivity will also have changed markedly, although not in every situation.

A final aspect of flexibility in a model like EPIC concerns the ability of such a model to represent what happens over a wide variety of climatic, physiographic, and agronomic conditions. As a requirement for the RCA process (PL 95-192), it was necessary to quantify how erosion affected productivity in not only the many cultivated cropping systems encountered in U.S. agriculture, but also on rangeland, irrigated cropland, and for 11 major crops on several thousand different soils. Thus, the model had to have the flexibility to work with such heterogeneous conditions.

Development of an Operational Model

The utility of any model depends upon

Ease of use,

Completeness of validation, and

Accuracy of prediction.

The ease with which a model can be operated obviously has much to do with its acceptance in the user community. In the vernacular of the computer community we must develop "user-friendly" computer programs. However, the problem often goes beyond the actual computer mechanics, and includes the need for direct prototype measurements which then become inputs to the computer model. If such measurements are extensive, they greatly increase the cost of model simulation. In the case of the EPIC model and its input for the RCA process, computer files were developed for the climate generator, soils data, and machinery operations, with the net result that the operation was streamlined immensely. In other instances, where parameter estimates were required but not widely available, the parameter was generated by other means, or a default value was used (with some sacrifice in accuracy).

Model validation is essential to any modeling effort. Unfortunately for the EPIC effort, data are essentially nonexistent for testing the model in its entirety. Furthermore, a model of this complexity is not directly amenable to experimental test. Thus, model validation consisted of (a) detailed testing of model components (subroutines) with observed data from a wide variety of experiments in some instances (e.g., the climate generator), (b) using widely accepted pieces of technology in other instances (e.g., the curve number and USLE submodels), and (c) more limited testing in other instances (e.g., some of the nutrient routines and Ritchie's evapotranspiration algorithm). To evaluate this model as a package, simulations were completed for a wide variety of locations, cropping systems, and management systems to observe whether the input and output data resembled what scientists expected in the region. Furthermore, tests were performed to see whether the model preserved the statistical properties of agricultural conditions for a region. This work led to numerous adjustments of model parameter values, and indicated some conditions for which the model needed modification. The simulation was repeated to observe if the new simulation was close to values expected in a region. Such user feedback is essential to the development, testing, validation, and acceptance of such technology and its importance cannot be overemphasized.

In this effort, as has been observed in other modeling development, our ability to conceptualize and model prototype conditions has progressed more rapidly than our ability to collect the *in situ* data for verification.

When Are Models Limiting?

The limitation for the use of models is closely related to the type of model being developed. For example, some models are intended to be site specific (e.g., most iconic and analog models, in other words, material models in Figure 1), whereas other models are intended to be of a general nature (e.g., the mathematical models in Figure 1). For mathematical models of an empirical nature, care must be exercised when extrapolating the results beyond the conditions for which the data was available to develop the model. An example of such an extrapolation is the extension of the USLE to rangeland and forested conditions with minimal pertinent data for parameter validation.

With theoretical mathematical models, the intent is to conceptualize a model and define the parameter values for a variety of conditions such that the model can be used without calibration. The intent with some of the recent Natural Resource Models developed in ARS was for this condition. Models like CREAMS (Knisel, 1980), EPIC, SPUR (Wight, 1983), and SPAW (Saxton et al., 1974) are intended for use without calibration, although the availability of data to test the simulation greatly improves the confidence of the user. Even with these theoretical models, care must be used when applying the model outside the context in which it was developed.

Finally, one other problem that is evolving with many natural resource models (we use this limitation because of our familiarity with them) involves the need for elaborate and detailed training as a basis for use of such models. Some of these models have become so complicated that it requires a highly trained scientist or engineer to use the technology. Some model developers seem to assume the work is done when the model is published in scientific literature, and are not willing to take the needed extra step to ensure development of user manuals, user-friendly pro- grams, etc.--the need for technology transfer.

Future Modeling Efforts

Future modeling trends are somewhat difficult to project, except for very short time frames, because of the dynamic nature of the computer hardware and software industry. Having received much of our formal training during the times of slide rules and electro-mechanical calculators, advances within the last three decades are astonishing. Computer storage that once occupied large rooms can now be contained on a single chip, so more miniaturization that can make a significant difference hardly seems possible, either in cost or weight. However, three things likely will occur in future models for agricultural applications.

1. Some farmers and other business people as well will use models in their daily operations.

2. There will be considerable effort to download large programs from mainframe computers to mini, or even personal computers, and many of these will operate in the field on portable computer units.

3. Artificial intelligence (AI) and a subset of it known as expert systems will play an increasingly important role.

These projections may seem conservative to many of you because we can already do many of these things, although the costs may not make all of them economical in 1985.

Artificial intelligence research has several goals, including the development of computational models of intelligent behavior, both its cognitive and perceptual aspects (Duda and Shortliffe, 1983). A more engineering-oriented goal of AI is the development of computer programs that can solve problems normally thought to require human intelligence. The field of AI consists of several areas, including speech recognition, language understanding, image analysis, robotics, and consultation or expert systems. This latter area is the one with the most immediate application in agricultural research (Michie, 1983) and, specifically, natural resource problem solving.

The goal of expert systems research is to provide tools that exploit new ways to encode and use knowledge to solve problems--not to duplicate intelligent human behavior in all aspects. The simplest, and generally the most successful, expert systems are classification programs. Their purpose is to weigh and balance evidence for a given case to decide how it should be categorized.

The identification and encoding of knowledge is one of the most complex and arduous tasks encountered in the development of an expert system. And in fact, the very attempt to construct a knowledge base often reveals knowledge gaps in the subject, as well as weaknesses in available representation techniques. A major effort in the development of the expert systems, then, is to overcome these gaps and to build a system where future knowledge can readily be introduced.

In summary, an expert system is one in which a nonexpert uses a computer program to help arrive at the same decision an expert would. An expert system is a way to "take advantage" of an expert's knowledge in some subject area and convert it, via a computer program, to assist in problem solving.

Summary

Erosion-productivity models have already had a significant impact on the RCA process (PL 95-192) in USDA. It seems likely that their role in the 1985 assessment will be even more dramatic; at least the results of the model simulation promise to be better than those of the 1980 effort.

The fact that models play an important role in RCA is not serendipitous; rather, it is a credit to those in RCA leadership who recognized the power of models to assist with problem assessment, problem analysis, and the consequent judicious management of our nation's soil and water resources.

We have introduced the subject of mathematical models, identified schemes for their classification, discussed problems encountered when using models, identified some modeling limitations, and finally made some projections regarding what we expect models to do in the future. The "sky seems to be the limit" in models, only restricted by our ability to collect prototype data to validate the built-in assumptions that limit such models.

References

1. DeCoursey, D.G. 1983. Mathematical Models: Research Tools for Experimental Watersheds. Research Oriented Workshop on Experimental Watersheds. U.S.-Uraguay Bilateral Cooperation. 30 pp. (In Press)

2. Duda, R.O. and Shortliffe, E.H. 1983. Expert Systems Research. Science 220(4594):261-268.

3. Johannsen, C.J. 1983. Resource Information for Conservation Decisions. J. Soil and Water Cons. 38(6):444-445.

4. Knisel, W.G. (ed.). 1980. CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. U.S.D.A., Science and Education Administration, Conservation Research Report No. 26, 643 pp.

5. Lane, L.J., and Woolhiser, D.A. 1977. Simplifications of Watershed Geometry Affecting Simulation of Surface Runoff. J. Hydrology 35:173-190.

6. Larson, W.E., Pierce, F.J., and Dowdy, R.H. 1983. The Threat of Soil Erosion to Long-Term Crop Production. Science 219(4584):458-465.

7. Michie, D. 1983. Introductory Readings in Expert Systems. Gordon and Breach.

8. Office of Technology Assessment. 1982. Use of Models for Water Resources Management, Planning and Policy. Summary, Six Chapters, and Appendix. U.S. Gov't. Printing Office, Washington, D.C.

9. Rosenblueth, A., and Wiener, N. 1945. The Role of Models in Science. Philosophy of Science XII, No. 4(Oct.), 316-321.

10. Saxton, K.E., Johnson, H.P., and Shaw, R.H. 1974. Modeling Evapotranspiration and Soil Moisture. Trans. ASAE 17(4):673-677.

11. Wight, J.R. (ed.) 1983. SPUR-Simulation of Production and Utilization of Rangelands: A Rangeland Model for Management and Research. USDA-ARS Miscellaneous Publication No. 1431. 126 pp.

12. Williams, J.R., Renard, K.G., and Dyke, P.T. 1983. EPIC-A New Method for Assessing Erosion's Effect on Soil Production. J. Soil & Water Cons. 38(5):381-383.

13. Woolhiser, D.A., and Brakensiek, D.L. 1982. Hydrologic System Synthesis. In: Hydrologic Modeling of Small Watersheds. ASAE Monograph No. 5, p. 3-18.

DESIGN, OPERATION, AND HISTORY OF EPIC

By Jimmy Williams

The Erosion Productivity Impact Calculator (EPIC) model was designed to determine the relationship between erosion and productivity. The EPIC model started with a meeting of several USDA agencies here in February 1980. At that meeting the National Soil Erosion Productivity Research Planning Committee was appointed. They developed the state-of-the-art paper "Soil Erosion Effects on Soil Productivity", a research perspective that was published in the Journal of Soil and Water Conservation. The third major step came in the development pnase at a meeting in September 1981 at Purdue. At this meeting, four thrust areas were formed--modeling, field experimentation, erosion mechanics, and conservation tillage. My remarks today will be limited to the modeling effort.

The modeling group was formed with a team of 14 researchers from three agencies and several locations throughout the country. The model was first reported operational in May of 1982 at an international symposium on ecological modeling at Fort Collins, Colorado. The latest major development to report is the completion of 15 to 20,000 runs for the 1985 RCA in December 1984.

In developing the EPIC model, the major objective was to develop a mathematical model for use in determining the relationship between erosion and productivity. To do that we felt the model needed to simulate the physical processes involved simultaneously and realistically using readily available inputs. The model also had to be capable of simulating hundreds of years because erosion can be a relatively slow process. We wanted the model to be generally applicable, computationally efficient, capable of computing effects of management changes, and operational by July 1, 1983, to provide information for the 1985 RCA.

Model Operation

The EPIC model is applicable to small areas because it assumes the soil, land use, management, etc. are essentially homogeneous. In the vertical direction, it allows up to ten soil layers, with variable thicknesses. It operates on a daily time step. And each time we have an erosion event, the eroded thickness is removed from the soil profile.

Various user options are provided by the EPIC model. Precipitation, temperature, and radiation variables may be input daily or the precipitation can be input and the other two generated. However, for most applications all three are generated. The RCA analysis was a good example of complete weather generation. Another noteworthy feature of the weather generator is its ability to repeat the same weather sequence at a particular site to properly evaluate various management strategies. Any number of weather sequences can be generated at a site to determine the effect of weather variation on a particular strategy. The output of the EPIC model can be obtained on a daily, monthly, or annual basis. We are able to simulate dryland, sprinkler, or furrow irrigation. Also, drainage systems are simulated. The EPIC farm machinery table includes about 100 pieces of equipment and the user can specify which to use in a particular simulation. Fertilizer may be applied at specific dates and rates, or it can be applied automatically as with the RCA version of the model. Water erosion is estimated by three different equations, and any one of the three can be designated as the one that interacts with the other components of the model. Wind erosion is also simulated. The EPIC crop loss which is not modeled by EPIC. You have to get away from the points and model the geometry of landscapes before you can tie all of this together.

J.Miranowski: It intrigues me that we have put a large group of scientists to work on EPIC over a number of years, and we've erred only on the side of underestimating the impact of soil erosion on productivity. I don't know of very many other cases where we have had a large group of recognized scientists where we have always erred on one side of the issue. Further, the EPIC efforts have been submitted to numerous peers for criticism.

Does EPIC consistently underestimate productivity impacts or is it simply that we have come up with some relatively low productivity impact estimates? And, where might we have erred on the side of overestimation, or is it just a one-sided err? I can think of a few cases from the economic perspective where the error may have gone in the other direction.

T. Robertson: In our review process, as I mentioned earlier, our soil scientists and agronomists were very skeptical in the beginning and very supportive of EPIC at the end of the review process. All through the process they kept saying we were underestimating erosion and yield impacts. They said we were underestimating basically because EPIC estimates the impact on a point. In some cases, the Dyke-Hagen Yield Soil Loss Simulator might be much better, because when they looked at the soil map units, they were getting the impact across the map unit. It was taking into consideration the nobs that are in Orangeville. We had an Orangeville pedon that we ran in EPIC at Temple. When it was reviewed, the soil scientists said that we were not going to get that high a yield on Orangeville. We got a high yield on Orangeville because we had a pedon out of the best part of the field. We didn't have the nob. This is one reason why EPIC underestimates erosion impacts. There may be some overestimations of impact, but I would say, in general, it is underestimating. That was the general feeling of our soil scientists and agronomists throughout the evaluation process. They were concerned about underestimating impacts. But EPIC is not underestimating what it is supposed to be estimating, namely the impact at a point.

K. Renard: Some comments are in order at this point regarding how models evolve and develop. There are stages to model development--in its first stage a modeling effort is revolutionary; and subsequently, it's evolutionary. EPIC went through the revolutionary stage a couple years ago and development now is evolutionary in nature. But one of the problems besetting us as the model evolves is that the conceptualization that takes place with many models such as EPIC is more detailed in its conceptualization, or in its mathematical formulation, than we can develop and design field experiments with which we can make the measurements to validate the model in its entirety. For example, as the model was first postulated and developed, we used some time tested principles, such as curve numbers, USLE, and so forth. We feel comfortable with these knowing something about such technology, but we know there are problems and limitations with them. In many of the other algorithms that are used in a model like EPIC, there have been experiments that have validated algorithms used at a specific site, and often only at a specific site. I'm sure the EPIC authors would say that the nitrogen/phosphorous routines certainly have never been validated over the entire range of problems that we are attempting to simulate with in this modeling process. Furthermore, we are using some technology that was developed in a crash because of time constraints. Now we have to use this technology to do a big job. But we are using technology that at this point is still unvalidated, and will evolve for many years to come. Ultimately this technology will probably be considerably changed from that which we are using today. A further point regarding the model evolution is that the version of EPIC being used in the 1985 RCA is the 12th or 14th or even the 20th version of EPIC and it's only 3 years old. An analogous situation involves SCS with the 9th approximation, 5th revision of the soil classification series or whatever the numbers are. Soil scientists are taking pot-shots at it and I'm sure that more evolutions of this soil classification scheme will be forthcoming. My end point is that we are talking about things that we really shouldn't be talking about. We don't know whether these model/classification schemes are right or wrong. We don't know whether the productivity reduction of five bushels per acre due to erosion is because we are on the mid-slope point or on the up slope point, or at the toe of the slope. Much of this technology is unknown because the research has never been validated as an entire package. Similarly, the EPIC model needs more validation based on field experiments but even without such validation, the EPIC model, with the known physics upon which it is based, is a sound scientific product.

J. Fletcher: Two points--first, the fertility is not being replaced. I don't have enough experience or knowledge to know that in general, but in at least one study we have done in Indiana where we did a number of sites on farmers' fields and looked at the fertility levels, I would say that is not true. The P and K levels, at least in much of the Corn Belt, are high enough that they are not limiting factors, even on eroded soil. I don't know how generalizable that is, but this was taken in one of the better corn growing areas in Indiana; we can take it for what it's worth.

Second--on slope, we are trying to do exactly that at Purdue. I am working in conjunction with George Foster at the Soil Erosion Lab, and Dave Beasley at Ag Engineering. We are looking at the impact of slope and slope shape and we are trying to combine using EPIC with some of the CREAMS-type models and answers. Another thing in that modeling effort--one of the problems in using EPIC in this particular effort is what do you do in the points of the slope where you get sedimentation and you get soil build-up. As far as we know, and I think it is true, is that it is not handled well in EPIC at this time, so we are making some (probably) horrendous assumptions and they may be somewhat accurate and they may be grossly inaccurate, but we will make them anyway.

Third, a technical point has to do with the way EPIC is being used with the random number generator when you are looking at P-0 and P-1 and the effects of no erosion and erosion on productivity. It is done with a single draw from a stochastic process over a 100-year time horizon and you have to point out that it is a single draw. And yes, it's been looked at as a reasonable weather pattern. But you have no idea what is really going on in the mean of that process, the way it's being used so far. It may be valid--it probably will not be a problem--but until you have looked at what is really going on in a statistical sense, you have to realize that there is a substantial question in that particular area that needs to be discussed.

J. Williams: It is unlikely that accumulated erosion during a 100-year period would vary appreciably for different 100-year weather sequences.

J. Putman: You might want to point out that the weather data sets that we have used have been checked to show no trends. We have eliminated that trend possibility.

J. Williams: I said this morning that EPIC is just a simple hillside model and we are not trying to account for differences in slope configurations or any of that sort of thing at this time. Not that we don't think these things are important, it's just that we tried to do what we could within a reasonable length of time.

C. Ogg: At the time RCA was conducted, there wasn't information about what soils are vulnerable and apparently that is still being developed. If you have a group of soils that you are concerned with, that are vulnerable and make up a small part of the cropland base--and you are not able to have a land group in your sampling that represents those soils--the sample may not represent them. In fact, the sampling procedure would appear to be biased against the vulnerable soils which benefit most from conservation.

and erosion on productivity are done with a single draw from a stochastic process over a 100-year time horizon. You need to point out that you are using a single draw that appears to represent a "reasonable" weather pattern. It should be noted that this does not necessarily represent the mean of that process. The series you are using may be valid--it most likely will not present a problem. However, until you have looked at what is really going on in a statistical sense, there is a substantial question in this area that needs to be discussed.

B. English: I just want to make one more comment. There's a whole other side to this thing, and that's the data needs of EPIC, and what data researchers are collecting. Again, if we have researchers in each state or even parts of states collecting data and putting it in this model, it would be nice if we had some kind of central store house to store some of this data. We need to make sure it was consistent before it went into the storing house so other researchers wouldn't have to go through what John went through in '83 collecting the data. We'd expand our data base because of the number of users using it.

K. Renard: I would like to make those of you in the audience who might not be aware that there are a couple of regional research committees in the land grant universities who are, in fact, involved in collecting and designing field experiments to provide validation for EPIC. One is NC126, if I remember right, and there's also the Southern Committee, SC126, both of whom have designed multi-state, multi-location experiments. They're experiments for multiple soils and for multiple cropping systems with the intention to provide validation data to test the EPIC and the PI models. There are also a number of ARS locations that are involved in some similar activities as well as in these regional committees.

A second point should be made with regard to a central clearinghouse for the EPIC model. I personally have some strong opinions that for some time into the future, this location needs to be tied very closely to the Temple location, and to those people who have been the prime architects of this effort. If I am correct, the model changes almost daily, so if somebody is intending to begin the use of this technology, it behooves that person to write directly to the Temple location to get a current version of not only the program but also the test data and the user's manual. If you get it from one of your cohorts, you're in all probability going to get an antiquated version that's not going to have all the most current information.

J. Putman: I also have some strong feelings in this area. I think we have to face the fact that over the next few years there are going to be many EPIC's at many levels of detail, and they'll drift quite far apart, perhaps, over time. This doesn't necessarily make any of them good, bad, or better. It merely means there are a lot of other applications. I happen to know of two. Texas A and M has a recent version of the interactive model and is tailoring it to Texas. Iowa State has a version. Iowa has an interdisciplinary committee developing a data bank which includes about 40 Iowa soils. I think 2 or 3 years from now they'll both be EPIC models, but I would expect the Texas A and M version to be vastly different from the Iowa State version. They probably should be, because the Texas version will emphasize local conditions in Texas. The Iowa model will emphasize important Iowa issues. I think the important thing is that somebody needs to keep track of the conceptual linkages to translate among these models but not wire them together and keep them identical. I think keeping the cutting edge of technology in the model depends on the user. Also, I would hope that someone gets a national version of EPIC, sort of an aggregate policy level model that probably will be quite different from the local models and not very useful at the local level. Nevertheless, everything that's known at the local level should feed into this. I see this going in many directions, and I think they're all good.

R. Follett: I want to reinforce what John's saying. This is part of the research process. I think Ken described it yesterday as revolution and evolution. It's important to season. The channels are usually shallow enough to move across. By fall or harvest, these same areas may show up again and may be 6 to 12 inches deep and several feet wide. Damage to harvest equipment may occur when the combine drops into an ephemeral gully and runs the nose of the combine into the ground or breaks some other part. The other aspect of ephemeral gully erosion is the long-term resource base productivity loss which occurs to an ephemeral influenced or contributing area. This area may be anywhere from a few feet to as much as 100 to 200 feet on each side of the ephemeral gullies. These contributing areas start experiencing yield declines as the soil is moved into the voided ephemeral area. This loss of productivity is much greater than the USLE-measured sheet and rill erosion damage discussed at this meeting.

In Nebraska, we have observed that the upper reaches of the ephemeral gullies extend into soils with less than 2 percent slopes. This observation suggests that the influenced area of ephemeral erosion might exceed the immediate area of the dendritic pattern.

The latter observation again points out the need for more research and modeling of ephemeral erosion processes.

K. Renard: I'd like to reply to what has been raised here. We in ARS have been concerned about ephemeral erosion as have a lot of the people in SCS. There is some ongoing work to address these problems. They're in various states of being available technology to address the problem, but let me back up a little bit. Two weeks ago we had two back-to-back work sessions at West Lafayette, Indiana, where SCS, ARS, and a bunch of other user and research groups, primarily some university people, got together. At those two sessions, we talked about a revision of the USLE Agricultural Handbook 537. The new handbook, we anticipate, will be available in its first draft, not in a final printed version, by the end of this calendar year. We feel pretty sure of this commitment because, for example, it will be presented at the winter meeting of the American Society of Agricultural Engineers in Chicago. The handbook will include some rather dramatic changes in the way cover management is handled. A lot of the management practices were developed from experiments with economic practices that are no longer prevalent. Grass basins were different. Plant canopies were different, and so forth, and we're finding that the cover management term to date often does not adequately reflect what is being experienced.

Now with regard to concentrated flow erosion, and I mentioned that there is some work being done to address that problem. It will not necessarily be included in this revision of 537. However, there is some technology today which can approach it, and that is the CREAMS model. That's one option that's available to you. There is some ongoing work, some experimental work in Ames, Iowa, with John Laughlin and a couple of his cohorts at Iowa State University for this problem of concentrated flow erosion. There is also some work being done at the USDA sedimentation laboratory at Oxford, Mississippi, in cooperation with Colin Thorne from Colorado State University, to provide a separate estimating algorhythm which then becomes sort of an add-on term to the USLE procedure for estimating this concentrated flow erosion routine. If I were given my druthers, I'd suggest that you use the CREAMS model, but the CREAMS model also requires quite a bit of concentrated effort to use and, therefore, for broad application planning purposes, it sometimes becomes difficult. Now the second part of that week we spent at Purdue, we concentrated on what we call second generation erosion technology, and this is what we anticipate in ARS and the research community as the erosion estimating technology that will replace USLE within a 3 to 5 year time frame. George Foster from our National Soil Erosion Laboratory is the leader of this effort, and we feel that we have this work fairly well under way and in hand and we think that within, for example, 3 to 5 years we will have such technology available. Some of the essential features of that technology will make it quite different from what's imbedded in Handbook 537. For example, we anticipate that it will probably operate on a lap-type computer or a portable computer that will be able to be taken into the field. Secondly, that the model would probably be hydrologically driven, and probably even have imbedded in it a climate generating routine. We think it will consider both rill and interrill erosion processes as contrasted to the lumped approach that's presently taken in the USLE, but that it will also include concentrated flow erosion such as you've mentioned being a problem in Nebraska. It will, therefore, be capable of taking not only the eroded material that is estimated to be dislodged at an upslope point, but also transport that material downslope and potentially down to a deposition point at the toe of a slope or transport it to some point in a stream and then represent some "small" (and I put that in quotes because it's ill defined) upstream homogenous response unit. In other words, we're not talking about applying it to something hundreds of acres in size where you might be faced with varying soils and many different types of agronomic systems, but we're talking about applying it to a field that might have some complex topography in it with some channel network, but probably have a relatively homogenous set of soils and agronomic practices associated with it. So that's kind of a nutshell of where we in ARS anticipate some of the next generation erosion technology going. Obviously, if that type of technology comes on board, that's going to give still a new challenge to the EPIC people, because it's going to be a major job to incorporate that into the EPIC model.

J. Putman: Let me change the tone of this and throw a challenge back to the foundation. Right now, we've talked about how important onsite and offsite is. We have discussed what a big job it is to put together a data set to run CREAMS. It's essentially impossible to put together a nationally consistent data set to run anything that goes beyond a point. I think modeling technology has far outdistanced data technology and information technology. And so, let me challenge SCS. ARS is building landscape models, let me challenge SCS to tiptoe through the tulips in the NRI and start generating landscape information on a national basis that the model can run on. One without the other is worthless at the national level, to do program and policy analysis. I understand how badly you want to talk about landscapes in the NRI.

J. Maetzold: I think that's one of our main purposes for having the meeting this afternoon--to coordinate some of this.

D. McCormack: As some of you know, we've had a national interagency soil-crop yield committee since 1975, discussing the opportunity to put crop yield data and accompanying soil and management data into a national data base. The ways in which this might prove to be useful have not been fully described, perhaps, but most people that were involved in the activity felt that ultimately the national aggregation of crop yield data should be of quite a lot of value. That work has proceeded rather slowly since 1975. At this time we do have a data form. A lot of people think it's not complete enough. But there is a data form, the software's been developed for handling the data in the data form, and data from small plot research, field trial research, or even data from farmer's fields are now being entered into that data base. It may be now actually be that the time has come, as Ken Renard suggested, that the national data base should be at Temple. But I think researchers concerned with any aspect of soil productivity should be familiar with this data base and contribute their data to it. It is a worthy activity, and I don't know anybody that's worked on it so far that's really seen the direction it ought to go, but somebody ought to really be thinking about it, I think, for future application.

D. Young: I will briefly comment on our experience during the last half year at Washington and Oregon in using EPIC. The work is funded by the Western National Technical Center of SCS. The purpose is to develop district-level managerial decision models for farmers, particularly to address the problem of switching over to annual cropping in traditional summer fallowing areas. The erosion rates are about three times as high on summer fallowed land as on annually spring cropped land. The kicker is that the yield and income risk are greatly increased when you switch to an annual cropping scheme. EPIC presents an attractive mechanism for looking at both the risk, in yields and incomes, and average yields and incomes. One can also use EPIC to introduce no-till or minimum tillage in conjunction with annual cropping. McCool (ag. engineering) and I (ag. econ.) are principal investigators on this project.

K. Renard: I have some problems with those aggregations that you did and the smoothing that's imbedded in them. I realize that for the sake of boiling that information down to something manageable, the data must be aggregated some way, but it's imperative that you also provide at that point in the report some information that tells a little bit about the variability that's imbedded within that aggregation. In other words, to present that aggregation and not tell about some of the inherent variability across major land resource areas is masking out the reality of what's happening on a specific farm or within a specific soil or within that land resource region. Don't give the reader of the RCA report the impression that those averages really mean what you are saying they mean. The well-adopted analogy applies here that if I'm standing with one foot in a bucket of ice and the other in a bucket of hot water, on the average I may feel OK, but I'm still in trouble. And that's the case that we're getting into when we start aggregating like we're doing. With regard to the wind and the water erosion, how you aggregate them is a problem. I suggest that you aggregate the two separately because, in all probability, given that you're having wind erosion, you're probably not having water erosion. They're occurring at different times, most likely. Therefore they're more or less distinct processes that are mutually exclusive, so if you're in a period or in a year where you've got excessive wind erosion, in all probability you're not likely to have a lot of water erosion. And vice versa. So you're probably going to have to aggregate those separately. Again, I would make a pitch that you include some illustrations that make that point.

J. Putman: We had an 8 1/2 by 11 bias in our examples because of the size of the overheads. They are intended to communicate quick answers to an audience. There will be, of course, some summaries by regions, but we hope to, at the very least, talk about the MLRA variability within the regions--where the high and the lows are. Did the crop aggregations bother anybody? We find that the data are little different and much more understandable with five crop groups instead of 17 crops. You can't believe what it does to the data cost when you mash a 17 x 17 matrix to a 5 x 5. But again, it makes a big difference, particularly in the Great Plains, when you present these potential losses, if you present the total loss from wind and water, as opposed to water erosion alone. That's why the Corn Belt jumped out so far yesterday, because we used water erosion only. The Great Plains is suffering some large amounts of wind erosion. Combining wind and water erosion will give a different picture.

K. Flach: I have strong viewpoints on wind erosion. I have a very good answer, John, and I think your statement isn't quite right, that the plant doesn't care whether it has lost the soil by wind or water erosion, because there's more selective erosion by wind erosion than by water erosion. But, be that as it may, try to keep them apart as long as you can. And then at the end put them together. According to the NRI, more than 1/3 of the total erosion in the country is by wind erosion, and therefore we've got to have it in there--it's a big factor. On the other hand, in looking over your data, on the soils and in the areas where we have high wind erosion, except for a few soils, the impact of erosion on productivity isn't very high. So it probably isn't going to make a lot of difference.

W. Fuchs: I said the impact of wind erosion is not very high on inherent productivity, but it is quite high on annual productivity.

J. Stierna: Let me just raise two questions about the issue between wind and water erosion. Do EPIC results show a greater sensitivity to an erosion event by water compared to wind and how sensitive is the impact of erosion on productivity as it relates to the time horizon?

J. Putman: This is a key point. The coefficients that we computed with regression analysis are based upon total soil loss over time. They must be, because in the 100th year the productivity change is not very sensitive to how soil was removed in the first 10 years. So